Electrooptic Propagation

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LONG TERM GOALS

Provide the navy with products describing the electro-optical propagation environment and atmospheric visibility (visible and IR) globally.

OBJECTIVES

The EO Propagation objectives are: 1) investigate, develop and evaluate fine and coarse mode aerosol models and their effects on visibility and target detection in visible and IR wavelengths 2) Integrate and develop simple, realistic extinction, scintillation and refractivity models for infrared propagation near the ocean surface, 3) develop and evaluate advanced marine radiance models that are compatible with TAWS and IRTSS 4) develop a consistent physical/chemical/optical model for aerosol particles suitable for inclusion in navy meteorological models.

APPROACH

Remote (surface-based and satellite) and in-situ (surface and airborne) sensors are used to measure the microphysical, optical and meteorological parameters from which models of aerosol-size distributions and sky/sea/terrain backgrounds can be developed and evaluated. Dr. Jeffrey Reid is the PI for the tasks in Marine Aerosol Measurements and Modeling and Dust Aerosol Measurements and Modeling. Dr. Stephen Doss-Hammel is the PI for the IR Transmission and Radiance task. Mr. Charles McGrath is the PI for the Coastal Radiance Modeling task and the Dynamic Target Wake Modeling task.

WORK COMPLETED

MARINE AEROSOL MEASUREMENTS AND MODELING

The bulk of the marine aerosol program for FY01 has been spent in preparation and execution of the Rough Evaporation Duct (RED) experiment. New hardware and aerosol sampling methods were

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developed for the accurate measurement of salt and fine mode particle fluxes. By the end of FY01, it is expected that 25 days of aerosol and meteorology data will be collected on the R/P Flip and 80 hours of airborne data will be collected from the CIRPAS Twin Otter for analysis in FY02.

An upgrade to the Navy's coarse mode aerosol models was also completed in FY01. The currently used Navy Aerosol Model had been developed for deck-height and cannot be applied to the near-surface environment below 10 meters. Therefore, the Advanced Navy Aerosol Model (ANAM) is being developed as an extension of the NAM/NOVAM to account for aerosols near the ocean surface. It is expected that ANAM will be the final module in the NAM series of regression models. The main activity in FY01 consisted of the statistical analysis of available experimental data to continue the ANAM development by the establishment / improvement of (empirical) relations between the aerosol concentration and the meteorological scenario.

Also in FY01 we initiated an EO TDA subtask. Sensor models such as EOTDA and TAWS evaluate the range at which the signal received by the sensor equals the threshold value for detection. This evaluation subtask involved (1) determining the zero-range contrast temperature difference of different types of combatant ships and their sea backgrounds in order to evaluate the performance ranges of airborne forward looking infrared (FLIR) passive surveillance systems, and (2) establishing a data base of the thermal characteristics of different types of ships to be compared to what is already in TAWS. For this effort, airborne measurements of IR ship signatures and their sea backgrounds have been obtained using an airborne AGEMA 900 dual-wavelength thermal imaging system. An algorithm has been developed using a modified version, SEARAD, of the Atmospheric Transmission/Radiance computer code (MODTRAN 2 or LOWTRAN) to retrieve the zero-range ship temperature and is currently being evaluated.

As an offshoot of the NAM/NOVAM validation work described above, we have begun exploratory research on using EO sensor data on targets of opportunity as a function of distance to back out target temperature and detection range. The idea behind this work is that if aircraft can perform a few point measurements on targets of opportunity while in route, reasonably accurate standoff or target detection distances can be determined.

As part of the ANAM development work done performed during FY01, the extensive Rotorod database was exploited to generate three separate data sets. These are a (composite) data set of observations at the Dutch MPN ("Meetpost Noordwijk") platform in the North Sea, a data set of North Atlantic observations and set of observations at the German FPN ("Forschungsplatform Nordsee") platform in the German Bight. All Rotorod spectra acquired at MPN and the North Atlantic were fitted to a lognormal distribution and a statistical analysis was performed to reveal relations between the lognormal parameters (amplitude, centre radius and width) and meteorological parameters. The lognormal distribution was added to the NAM-model as a 4^{th} mode: the extended model was named the Advanced Navy Aerosol Model (ANAM), version 3.0. Using the lognormal parameters from the statistical analysis as a starting point, the 4^{th} mode parameters were tuned to have maximum overlap of the ANAM-predicted and experimentally observed aerosol concentrations. The final 4^{th} mode lognormal distribution is characterized by a fixed width, a center radius that depends on the relative humidity according to a Gerber growth curve, and an amplitude that depends exponentially on wind speed and height above mean sea level.

IR TRANSMISSION AND RADIANCE

A new broad-beam transmissometer source was acquired, tested, and calibrated for use in floating platform transmission field tests. For this type of test, one end of the transmission link is a floating platform that cannot be stabilized to the degree required by a conventional narrow-beam transmission source. The broad-beam source was acquired to enable participation in the RED (Rough Evaporation Duct) test in Hawaii which utilizes the floating platform FLIP as the transmission source point. We completed transmission measurements during the Rough Evaporation Duct (RED) experiment.

We have completed an analysis of transmission data from the Electro-optical Propagation Assessment in Coastal Environments (EOPACE) experiment off San Diego. One of the driving considerations for this analysis is the appearance in field test data of signal values well in excess of free-space levels for extended periods of time (30 minutes or more). To identify the reason for these high signals we calculated all of the contributing factors in the signal transmission process. The extinction due to absorption and scattering was calculated using MODTRAN for molecular extinction, and particle extinction was estimated by application of Mie theory to the continuous particle size distributions measured at one endpoint of the transmission path.

COASTAL RADIANCE MODELING

A model of the IR radiance of water background was completed and transitioned to TAWS 3.0. Algorithms were developed to account for radiance variability in the coastal zone due the effects of sea surface temperature variance, non-homogeneous cloud distributions, and coastline land presence behind the water background. This task is complete in FY01.

DUST AEROSOL MEASUREMENTS AND MODELING

At the end of the previous fiscal year we conducted a large field program in Puerto Rico. The Puerto Rico Dust Experiment (PRIDE) took place at Roosevelt Roads Naval Station, PR, from June 27-July 25, 2000. For this study a group of Navy, NASA, and university scientists conducted a combined surface, airborne, satellite and modeling campaign in an effort to measure the properties of African dust transported into the Caribbean. There are two principal tasks:

1) Determine the extent to which the properties of dust particles and the spectral surface reflectance of the ocean surface need to be known before remote sensing systems can accurately determine optical depth and flux.

2) Evaluate/validate the skill in which the Naval Research Laboratory's Aerosol Analysis and Prediction System (NAAPS) predicts the long-range transport and vertical distribution of African dust.

In FY01 we completed a preliminary analysis of the data, and completed PRIDE's two principal tasks.

DYNAMIC TARGET WAKE MODELING

This task is a new start in FY01. The Point Sur (gunboat) target in TAWS was converted from the older EOTDA format to the MuSES format needed for the later versions of TAWS. A new thermal

Figure 1. Turbulent wake and kelvin wave system generated by a ship.

infrared target wake model was developed for the gunboat suitable for use in the MuSES target builder and eventually in the TAWS prediction model. Airborne infrared field measureme nts were made of the Pt Sur in the Santa Barbara area and also targets of opportunity in Southern California. From initial analysis and first looks at the data it is apparent that more data cases are needed to scale the new TAWS parametric model than originally anticipated. Figure 1 is an example of the wake created by a small ship as seen from air. The ship is sailing toward the bottom of the picture with the turbulent wake extending aft. The kelvin wave system flares outward in arrowhead fashion as it extends backward. In the IR, these wakes may be far more easily detectable than the ship itself.

RESULTS

MARINE AEROSOL MEAUREMENTS AND MODELING

In order to evaluate the EO sensor models being used by the Navy, we used 5 test cases of ship/background contrast data sets previously collected by C. McGrath of D858. In all cases the EO prediction models overpredicted target/background temperature contrast (i.e., over predicted visibility). Generally, this overprediction was on the order of ~25%. The largest uncertainty (~35%) was associated with the smallest vessels (e.g., the R/V Point Sur), while lowest (~20%) was in the largest vessels (e.g, LHD). This suggests that at least part of the discrepancy was in the modeling of the Agema sensor itself and that small ships at large distances became sub-pixelized.

A difficulty in the propagation model itself was also detected. First, the extreme sensitivity of the model to the input of dew point or specific humidity can cause large error bars. A 2 degree Celsius error in input dew point (about the limit of most meteorology models) can cause a 25% change in target detection range for the Agema wavelengths. More importantly, however, this study suggests that NAM and NOVAM are underestimating the impact of coarse mode salt particles on EO

propagation. It appears likely that the salt modes in these models are too small relative to other measurements in the literature. This discrepancy will be studied during the RED field campaign.

The ANAM-3.0 reproduces the measured Rotorod concentrations to within a factor of 3-4 for the data sets that have been used to develop the model (MPN and North Atlantic), and to within a factor of 5.5 for the independent data set (FPN). In general, and in particular for larger ($R > 10$ μm) particles, the ANAM performs better than the NAM. The ANAM yields about equal predictions as the NAM at 30 m height. Below this height, the ANAM extinction is up to 4 times higher than the NAM extinction. The effect of the 4^{th} mode is most visible at infrared wavelengths and at high wind speeds.

IR TRANSMISSION AND RADIANCE

We have demonstrated that a refractive propagation factor is a critical component of an accurate transmission model within the marine surface layer. The propagation factor is a multiplicative quantity that is derived entirely from the local refractive field and the geometry of the entire transmission system.

DUST AEROSOL MEASUREMENTS AND MODELING

During the PRIDE field study, mid-visible optical depths in Puerto Rico averaged 0.3, with a maximum of 0.6 and with clean marine days at ~0.08. Towards the end of the study period (in the middle of the summer dust transport season), the vertical distribution of dust was similar to those found in BOMEX in 1969. Dust concentrated in the Saharan Air Layer (SAL) aloft in agreement with the common conceptual model of dust transport into the region. However, during the first half of the study period, dust had the highest concentrations in the marine and convective boundary layers with lower dust concentrations aloft despite the presence of a strong SAL. In fact, the highest dust concentrations found over the whole study period were below the trade inversion, opposite to what is generally assumed for the region. We did not find a consistent correlation between atmospheric sounding characteristics (such as inversion strength and water vapor mixing ratio) and dust vertical distribution. The factors influencing the vertical distribution of dust are unclear, although supporting meteorology suggests that conditions on the coast of Africa influence (in particular the strength of the seasonal monsoon) the nature of the vertical distribution of dust once it arrives in the Caribbean.

We have performed an extensive analysis of the NAAPS model results and compared those to the vertical distribution of dust in the Caribbean. While NAAPS performed well in determining the relative concentration of dust spatially, it had difficulty reproducing the proper vertical distribution in Puerto Rico. At this point in time we feel that the difficulty lies in the vertical resolution of the NOGAPS model data, which NAAPS is based on. With only 20 levels, NOGAPS cannot capture the relative strength of inversion, in particular with the development of the trade inversion over the tropical Atlantic.

IMPACT/APPLICATIONS

Radiative transfer models originally developed for open water use are simply not applicable during coastal actions where the atmospheric structure and constituents vary considerably. This directly impacts the performance of the MODTRAN based models, which the navy heavily uses to predict EO performance. The products from the EO propagation project are applicable to the Navy's meteorology, sensor performance assessment systems and sensor/system development projects. They are directly

applicable to TAWS that will be integrated into Navy NITES-2000 package. Also, the SeaPlus model relates directly to IRTSS.

TRANSITIONS

Parameterizations for the determination of dust concentration and slant path visibility from remote sensing systems will continue to be transitioned to the Marine Meteorology Division of NRL Monterey for further development and possible implementation. This work will also lead to the development of dust aerosol models that will be made available for inclusion in the Air Force MODTRAN propagation and TAWS (Target Acquisition Weather Software) codes.

An IR radiance water background model was transitioned to TAWS 3.0 as a result of the completion of the Coastal Radiance Modeling task.

RELATED PROJECTS

This project is related to NRL Monterey's mesoscale and data assimilation model projects, their program for improving the current TAWS, and the COVAMP project. This work relates directly to the TAWS and IRTSS projects as described above. Tri service coordination is conducted under the Technology Area Review and Assessment.

SUMMARY

The Electrooptic Propagation Project is divided into five areas of investigation: (1) the effects of marine aerosols on propagation through the atmosphere 2) near ocean surface IR transmission and radiance, (3) marine electro-optical scene radiance modeling, (4) effects of dust aerosols on IR propagation, and (5) modeling atmospheric effects upon the infrared wake signatures of ocean targets. We have collected dust aerosol data to advance the knowledge of transport of dust in the atmosphere; we expect data from the RED experiment to validate and improve our characterization of aerosols in the marine surface layer. Analysis of EOPACE transmission data shows that refractive effects, in addition to molecular and aerosol attenuation, is an important component of IR transmission. Refraction may further reduce transmission but also may focus the energy above the level that would exist in the presence of molecular and aerosol attenuation alone.

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